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PERTHITES

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ABSTRACT

No one theory of the origin of perthitic feldspars is adequate because there are several processes capable of forming these intergrowths. There are processes obtaining under magmatic conditions which produce perthites by several kinds of exsolution. Other perthites are formed by deuteric solutions, others by pneumatolytic agents, still others by hydrothermal mineralization. There may be perthites formed by cold waters under vein conditions.

Andersen's suggestion that the anisotropic coefficient of contraction produces cooling and cleavage cracks which furnish both the orientation and the space for perthitic blebs is very plausible.

Vogt's 1926 thermal diagrams are discussed. His diagram showing a series of solid solutions with a minimum with inclined solubility curves, even though it does not show polymorphism, is as satisfactory as any.

A classification of perthites is offered in a temperature basis, using terms of Mäkinen and Andersen. The nomenclature of perthites is outlined with suggestions for a more specific terminology.

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INTRODUCTION

For the purpose of presenting the status of the origin of various perthites to my students in petrology, I summarized the ideas I have previously offered, together with the recent opinions of Mäkinen,¹ Vogt,² Andersen,³ and Spencer.⁴

As this attempt apparently makes these problems easier to visualize, I have assumed that others would like to have it in available form, and therefore I am presenting it in this paper.

PERTHITES OF MANY ORIGINS

A study of the literature clearly shows that many perthites are secondary in origin; albitic blebs are believed to have been introduced from without⁵ by later mineralization and replacement, Colony⁶ even suggesting "injection perthite." There has been a decided trend of thought in this direction for some time. It is natural that some should favor lower temperatures and secondary processes for the formation of all perthites. There is, however, abundant evidence that some intergrown feldspars are high temperature phenomena. The term "secondary" is such an unsatisfactory one, that I shall try to get along without using it.

Andersen⁷ recognizes a number of different textural characteristics of perthitic blebs, which I will discuss later, some of which he believes are due to exsolution.⁸ As exsolution is a relatively high temperature phenomenon, I shall begin by discussing perthites of magmatic origin.

MAGMATIC PERTHITES

The most satisfactory way to grasp the process called exsolution is by the use of thermal diagrams. As a matter of fact, we do not

¹ Mäkinen, E., Über die Alkalifeldspate: *Geol. Fören. Förhandl.*, vol. XXXIX, 1917, pp. 121-184.

² Vogt, J. H. L., *Norsk. Videnskaps Akademi, Oslo. Mat. Naturvid.*, No. 4, 1926, pp. 87-101.

³ Andersen, Olaf, The Genesis of Some Types of Feldspar from Granite Pegmatites: *Norsk. Geol. tidsskrift*, B. X, h. 1-2, 1928, pp. 116-205.

⁴ Spencer, Edmondson, A Contribution to the Study of Moonstone from Ceylon and Other Areas and the Stability-Relations of the Alkali Feldspars: *Min. Mag.*, vol. XXII, 1930, pp. 291-365.

⁵ Wenglein, O., *Aug. Diss.*, Kiel, 1903. Warren, C. H., *Am. Acad. Arts & Sci.*, vol. LI, 1915, p. 143.

⁶ Colony, R. J., The Final Consolidation Phenomena in the Crystallization of Igneous Rocks: *Jour. Geol.*, vol. XXXI, 1923, pp. 170-171.

⁷ *Op. cit.*

⁸ Alling, H. L., *Jour. Geol.*, vol. XXIX, 1921, p. 222. Especially the footnote.

possess an accurate one. There are many obstacles in getting what is much desired. However, there are many theoretical diagrams, nine of which I have reproduced in Fig. 1. I shall not attempt a thorough discussion of these as this has been done before, but will merely outline the opinions offered by Vogt and Spencer in their recent papers.

Vogt⁹ believes that the potash-soda feldspars belong to type III (with a minimum¹⁰) or type V (with eutectic). However, in 1905¹¹ he drew the eutectic gap much too large as he himself states in 1926. Mäkinen¹² made the miscibility gap cover about 10 percent (by weight) which is "greatly exaggerated," meaning, if I have interpreted him correctly, that his conception of the diagram is a eutectiferous one closely approaching type III. With this clue, Vogt¹³ offers diagrams, which I have copied as Fig. 1, E and F, showing in reality how type V, as he conceives it, closely resembles type III.

Ussing¹⁴ and Beljankin¹⁵ have objected to Vogt's original diagram as not quantitatively accurate. This comment applies with almost equal force to all the others as well.

Now it is significant that Vogt's early diagram with a wide miscibility (eutectic) gap was based upon granitic, and hence plutonic feldspars, which Mäkinen recognizes as having a broader compositional range than pegmatitic feldspars. I attempted to explain this difference in range through undercooling, a phenomenon which Bowen,¹⁶ in his discussion of the feldspar diagram, does not mention. Elsewhere he states that "a detailed study of the effects of viscosity and under-cooling . . . would be of some interest to the petrologist . . . Undercooling must be regarded as an unimportant

⁹ Vogt, J. H. L., *Norsk Videnskaps Akademi, Oslo. Mat. Naturvid.*, No. 4, 1926, pp. 87-101.

¹⁰ See Dittler, E., *Tscherm. Min. Petro. Mitt.*, vol. XXIX (1910), and XXI (1912), p. 513.

¹¹ Vogt, J. H. L., *Tscherm. Min. Petro. Mitt.*, vol. XXIV (1905), pp. 437-543.

¹² Mäkinen, E., *Über die Alkalifeldspäte: Geol. Fören Förhandl.*, vol. XXXIX, 1917, pp. 121-184.

¹³ Vogt, J. H. L., *Norsk Videnskaps Akademi, Oslo, I, Mat. Naturvid Klasse*, 1926, No. 4, fig. 15, a and b, p. 88.

¹⁴ Ussing, N. V., *Geology of the Country around Julianehaab: Meddelelser om Grønland*, 38, 148, 1911.

¹⁵ Beljankin, D., *Ausscheidungsfolge der Feldspäthe in den Granitgesteinen: Ann. Inst. Polytechn. Pierre le Grand à Petrograde*, 22, 1914, pp. 259-277.

¹⁶ Bowen, N. L., *Evolution of the Igneous Rocks*, Princeton, 1928, pp. 227-231.

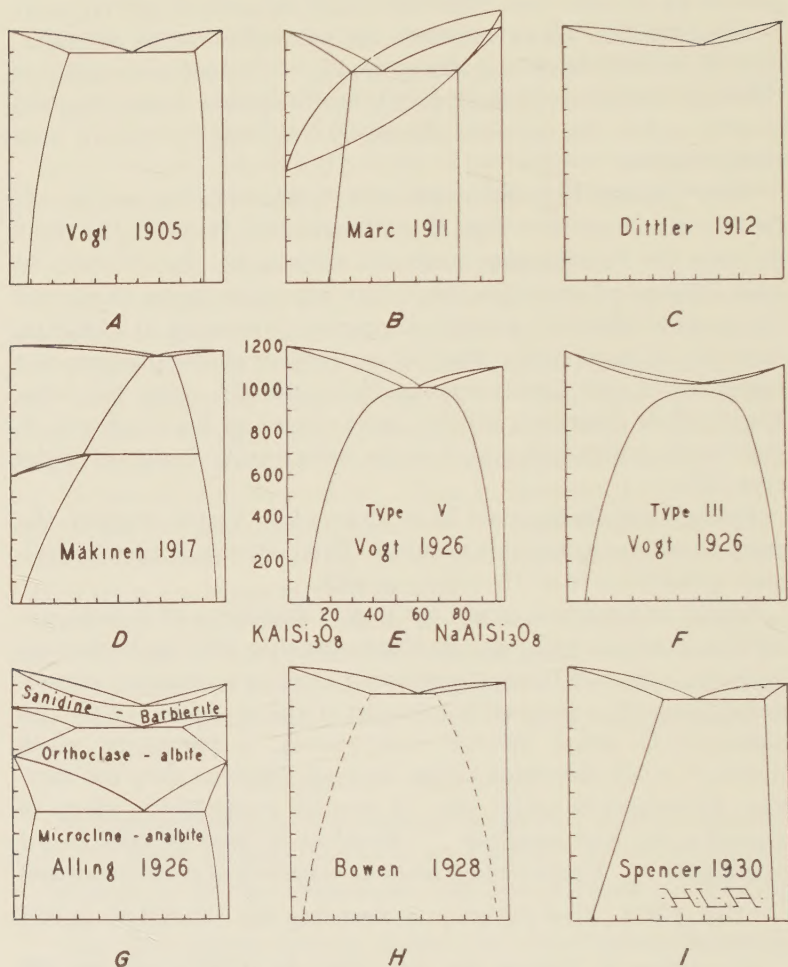


FIG. 1. A collection of thermal diagrams of the potash-soda feldspars showing the diversity of opinion. They have been drawn to the same scale.

A. Vogt, J. H. L., *Tscherm. Min. Petro. Mitt.*, vol. **XXIV**, 1905, p. 437.

B. Marc, Robert, *Chemische Gleichgewichtslehre*, 1911, p. 102. The diagram was scaled off on the basis of 1200° C. for the incongruent melting point of potash feldspar and 0° C. for the base. Hence the temperature scale is only approximate.

C. Dittler, E., *Tscherm. Min. Petro. Mitt.*, vol. **XXXI**, 1912, p. 513.

D. Mäkinen, E., *Geol. Fören. Förhandl.*, vol. **XXXIX**, No. 2, 1917, pp. 121-184.

E. & F. Vogt, J. H. L., *Norsk. Videnskaps Akademi, Oslo, I Mat. Naturvid.*, No. 4, pp. 88-91, 1926.

- G. Alling, H. L., *Jour. Geol.*, vol. **XXXIV**, 1926, pp. 591-611. Suggested by data of Kôzu and Saiki.
- H. Bowen, N. L., *The Evolution of the Igneous Rocks*, 1928, p. 228. "As the relations are ordinarily assumed to be." I have added the solubility curves.
- I. Spencer, Edmondson, *Min. Mag.*, vol. **XXII**, 1930, p. 327. Modification of Vogt's and Warren's diagram to explain the crypto- and microperthites, moonstones of Ceylon.

consideration . . . because . . . colossal masses of magma have been subjected to cooling at a rate which *precludes* undercooling."¹⁷ (My italics.) In Fig. II, I have reproduced Spencer's diagram, which is Vogt's early one, modified to fit the moonstones of Ceylon. It seems unfortunate that Spencer did not use Vogt's 1926 diagram, type III, which in many ways, even though it does not show polymorphism, is as satisfactory as any offered up to the present.

The theory of simultaneous crystallization of blebs and host in forming perthites implies, although not necessarily, eutectic relations. It is perhaps natural to seek comparisons in the field of metallography. Metallic alloys unquestionably exhibit many textures that are due to simultaneous crystallization. Metallic intergrowths of this origin are usually not orientated in contrast to many perthites. Desch¹⁸ contrasts metallic and silicate melts in respect to the dominance of eutectics. In alloys they are very important. They appear to be much less common in igneous rocks. He suggests the following differences:

TABLE I
DIFFERENCES BETWEEN:

Metallic Alloys	Silicate Rocks
1. Slightly associated	Highly associated
2. Low viscosity	High viscosity
3. Ease of diffusion	Diffusion very slow
4. Undercool slightly	Undercool easily
5. Many eutectics	More solid solutions
6. Eutectic textures	Eutectic systems may not show textures
7. Dominant eutectic textures	Some fine grained aggregates equivalent to eutectic textures

¹⁷ Bowen, N. L., *The Physical Chemistry of Igneous Rock Formation: Trans. Faraday Soc.*, No. 60, vol. **XX**, 1925. The Reaction Principle, p. 478.

¹⁸ Desch, C. H., *The Theory of Crystallization in Rock Magmas: Trans. Faraday Soc.*, No. 60, vol. **XX**, 1925, pp. 469-473.

These characteristics, outlined by a metallographer, and hence perhaps more significant, show how cautious the petrologist must be in judging origins of textures on mere appearances.

EUTECTIC PERTHITES

If perthites are due to eutectic relations it calls for type V which is the type of diagram nearly all of the investigators suggest. But if the relations are characterized by type III after Fig. 1-F, then such intergrowths are not eutectic.

If a parallel from metallic alloy eutectics is made, the lack of orientation of the blebs and spindles suggests that perthites are not eutectics because the latter are usually orientated. But there is this further difference between metallic and silicate alloys; many commercial metals possess cubical symmetry and hence their thermal expansion is the same in all directions. The thermal expansion of feldspars on the other hand, as their monoclinic and triclinic habit implies, differ along crystallographic axes. Internal strains in a cooling feldspathic crystal cause contraction cracks to develop, furnishing both a place and an orientation for eutectic melts.

It is conceivable, of course, that there are eutectic perthites. Intergrowths of quartz and feldspar in graphic granite and in myrmekite¹⁹ have been interpreted as eutectic textures by some²⁰ and denied by others.²¹ If eutectics why not perthite? I have not satisfied myself that there are true eutectic perthites.

EUTECTOID PERTHITES

Let us investigate the possibility of eutectoid relations. Perhaps the term needs a word in explanation. Binary eutectics mark a change in solubility with falling temperature from a mutual liquid solution to a two phase system where the phases are solids with limited solubility towards each other. Similarly, binary eutectoids are produced from a mutual solid crystalline solution consisting of a single phase into a system composed of two solid phases.

There has been an equilibrium diagram of the potash-soda feldspar system published that shows eutectoid relations.²² Such a dia-

¹⁹ Sederholm, J. J., *Bull. de la Comm. Geol. de Finlande*, No. 48, 1916.

²⁰ Harker, Alfred, *The Natural History of Igneous Rocks*, 1909, pp. 270-272.

²¹ Schaller, W. T., *The Genesis of Lithium Pegmatites: Am. Jour. Sci.*, (V) 1925, pp. 269-279.

²² Alling, H. L., *Jour. Geol.*, vol. XXXIV, 1926, p. 602, fig. 2; p. 607, fig. 5.

gram, by the nature of the case, is hypothetical. Such devices to explain perthites presuppose polymorphism of either one or both of the end members of the system under discussion. Polymorphism of orthoclase and albite is a working theory not proved nor universally acceptable.²³ Nevertheless, if granted, then eutectoid perthites are not only possible but probable. The orientation of the blebs, controlled by cooling and cleavage cracks, seems highly plausible. I am inclined to believe that many actual specimens of perthite which I have seen are perhaps better explained as eutectoid textures rather than eutectic intergrowths. Such specimens are not pegmatitic feldspars. And it is well to insist, for the sake of rigorous thinking, that different perthites in different petrological "habitats" presumably have different origins.

EXSOLUTION PERTHITES DUE TO POLYMORPHISM

Again polymorphism is assumed. The inversion point marks a decrease in solubility of one solid solution for another. Such a condition is pictured by Warren,²⁴ and Harker.²⁵ Such a conception is, I believe, a reasonable one and may account for some perthites. However, this theory of exsolution due to polymorphism should be distinguished from other theories involving exsolution. See Fig. 1-G.

EXSOLUTION PERTHITES DUE TO INCLINED SOLUBILITY CURVES

The usual concept conveyed by the term exsolution is that process of crystal separation by decrease in solubility with falling temperature, as is indicated by inclined solubility curves in a thermal diagram. Such a theory is dependent upon phase rule diagrams but is independent of polymorphism. Hence if potash feldspar is monomorphic, as it may be, then some perthites are due to separation because of decrease in solubility with falling temperature. This is a process I have suggested for many feldspars²⁶ but not for all. In this respect Megathlin²⁷ is mistaken in thinking I would assign all pegmatitic perthites to exsolution when he says: "This relation-

²³ Vogt, J. H. L., *Norsk. Videnskaps Akademi, Oslo, I. Mat. Naturvid.*, No. 4, 1926, p. 13.

²⁴ Warren, C. H., *Am. Acad. Arts & Sci.*, vol. L1, 1915.

²⁵ Harker, Alfred, *The Natural History of Igneous Rocks*, 1909, p. 256.

²⁶ Alling, H. L., *Jour. Geol.*, vol. XXIX, 1921, p. 222. Especially the footnote.

²⁷ Megathlin, G. R., *The Pegmatite Dikes of the Gilsum Area, N.H.: Econ. Geol.*, vol. XXIV, 1929.

ship has been claimed by Alling²⁸ to be due to exsolution and not to replacement." Megathlin refers to my early paper.²⁹ There he will find I am discussing the theory of exsolution with the aid of Warren's³⁰ diagram and applying it to the feldspar described by Smyth³¹ as occurring in a *plutonic* igneous rock and not to a pegmatite. Megathlin will find in a subsequent paper³² a definite reference to "secondary changes taking place following primary deposition." Here hydrothermal replacement would be cataloged.

It would be well for us to remember that the choice of theories of the genesis of perthite depends upon the geologic "habitate" of the feldspars in question, for I am confident that different processes are responsible for different perthites. To distinguish between these different perthites is often a difficult task.

THE ORIENTATION OF BLEBS

The perthite from its "type" locality³³ was described as follows: "the albite plates are polysynthetically twinned and parallel or approximately parallel to the *a*-axis."³⁴ Other directions for albitic plates in intergrown feldspar from Perth, Ontario, Canada, are parallel to the (110) face. Since then many other orientations have been noted.

All feldspars have good cleavage-planes, one parallel to (001) and another parallel to (010). Other cleavages are known but less common. Andersen³⁵ suggests that the maximum expansion, and hence contraction, in alkali feldspars³⁶ lies in the plane of symmetry

²⁸ *Op. cit.*

²⁹ Alling, H. L., *Jour. Geol.*, vol. **XXIX**, p. 222, 1921.

³⁰ Warren, Charles H., *Proc. Am. Acad. Arts & Sci.*, vol. **LI** (1915), pp. 125-154.

³¹ Smyth, C. H., Jr., *Trans. New York Acad. Sci.*, vol. **XII** (1893), p. 204.

³² Alling, H. L., *Jour. Geol.*, vol. **XXXIV** (1926), p. 593.

³³ Thomsen, 1832, *Shep. Min.* (1) 232, "Interlamination of Orthoclase and Albite. First considered a variety of orthoclase."

³⁴ Rogers, A. F., Observations on the Feldspars: *Jour. Geol.*, vol. **XXI**, 1913, p. 203.

³⁵ Andersen, Olaf, The Genesis of Some Types of Feldspar from Granite Pegmatites: *Norsk Geologisk tidsskrift*, B. **X**, h. 1-2, 1928, pp. 116-205. See Review by H. L. Alling, *Am. Mineral.*, **14**, 1929, pp. 241-242.

³⁶ See Schmann, J., Über die Mikroclin und Perthitstruktur der Kalifeldspathe und Abhängigkeit von äü Beren. z. Th. mechanischen Einflüssen: *Jahresber. Schles. Ges. Vaterl. Cultur*, vol. **63**, 92-100 and vol. **64**, 119, 1886.

Fizeau, H., Über die Ausdehnung starrer Körper: *Pogg. Ann.*, vol. **135**, 383-390, 1868.

Beckenkamp, J., Über die Ausdehnung monosymmetrischer und asymmetrischer Krystalle durch die Wärme: *Zeit. Kryst.*, **5**, 452-461, 1881.

(assuming these feldspars to be monoclinic), at an angle of 18–20° to (001) and the direction of minimum expansion (and contraction) is usually along the *b*-axis (010). The curves of Kôzu and Saiki³⁷ show, as earlier investigators have established, that the maximum expansion (and contraction) parallel to (001) is very considerably greater than in other directions. But it must not be inferred that stresses of cooling in natural rocks is sufficiently rapid to exceed the internal strain to produce abundant fractures. The bulk of even extrusive flows is so great, the cooling of a lava is slow,³⁸ and hence if the cracks are formed they occur in spite of the very gradual fall of temperature. It can, however, be suggested that a more rapid rate of the loss of heat occurs in dikes and pegmatites; the large size crystals of the latter being due to volatile constituents.

Now Andersen³⁹ assures us that "the direction perpendicular to the axis of maximum expansion coincides with one of the prominent directions of orientation of perthite intergrowths." He further discusses the effect of strains set up not only within feldspar grains by cooling but by being enmeshed with adjacent crystalline masses of quartz in granitic pegmatites, the different behavior of quartz in the matter of coefficient of cubical expansion. The work of Sosman,⁴⁰ and Kôzu and Saiki⁴¹ show that the transformation point of $\alpha \rightarrow \beta$ quartz is marked by various directions. Below 575°C. (at one atmospheric pressure) quartz expands in a similar fashion to that experienced by feldspar, but above that temperature the curve flattens out and actually drops showing, on heating, a contraction. Because of the strong adhesion between quartz and feld-

Offret, A., De la variation, sous l'influence de la chaleur, du indices de refraction de quelques especes minerales, dans l'etendue du spectre visible: *Bull. Soc. Franc. Min.*, **13**, 614–644, 1890.

Kôzu, S., and Saiki, S., The Thermal Expansion of Alkali Feldspars: *Sci. Rept Tôhoku Imp. Univ.*, Ser. III, vol. II, pp. 203–238, 1925.

Kopp, H., *Liebig's Ann.*, Suppl. 3, 289, 1859.

Pfaff, F., *Pogg. Ann.*, **107**, 148, 1859.

Von Fedorov, E. S., *Zeitsch. Kryst.*, **28**, 486, 1897.

Joly, J., *Trans. Roy. Soc.*, Dublin, (2) 6, 283, 1897; 41, 250, 1887.

³⁷ *Op. cit.*

³⁸ See N. L. Bowen, Diffusion in Silicate Melts: *Jour. Geol.*, vol. **XXI**, 308, 1921.

³⁹ *Op. cit.*, p. 131.

⁴⁰ Sosman, R. B., The Properties of Silica: Chem. Cat. Co., N. Y., 1927, pp. 360–415.

⁴¹ Kôzu, S., and Saiki, S., *Sci. Rept. Tôhoku Imp. Univ.*, Ser. III, 1925, vol. 2, pp. 203–238.

spar in acid igneous rocks, this peculiarity of quartz, Andersen argues, would stress the feldspar beyond its elastic limit. Now the strength of feldspar is likewise a vector function. I have not at hand any quantitative data but suppose that the planes of cleavage and parting are planes of weakness. As above noted, cleavage is very distinct parallel to the (001)-face and less so parallel to the (010)-face. Parting is often parallel to the (100)-face and sometimes is parallel to a hemi-orthodome and inclined a little to the orthopinacoid.

TABLE II
CLEAVAGES IN POTASH FELDSPAR AND ORIENTATION OF PERTHITIC BLEBS

Face	Face	Cleavage	Expansion	Parting	Blebs
<i>a</i>	(100)		Max. +18–20° from (100)	to (100)	“normal” or nearly to (100). Perth, Ont.
<i>b</i>	(010)	to (010) imperfect	Minimum to (010)		+6.5–6.5° to (010)
<i>c</i>	(001) Basal Pina- coid	to (001) perfect	Mean 6°–8° from (001) ⊥ to (010)		to (001) nearly ⊥ to (010)
<i>m</i>	(110) Prism	to (110) and (1 $\bar{1}$ 0) separation			to (110) “Peculiar”
<i>x</i> and <i>y</i>	(110) and (201) Hemiortho- domes			to a hemi- orthodome and inclined to the ortho- pinacoid	
Δ	(13.0. $\bar{2}$) (320)				to (13.0. $\bar{2}$) ⁴² (320) ⁴²

On consulting Table II, giving data compiled from various sources, the reader will note that while there is some relation between the direction of expansions and planes of perthitic blebs, there are enough inconsistencies to weaken the suggestion that

⁴² Spencer, Edmondson, *Min. Mag.*, vol. XXII, 1930, p. 362.

there is always a direct relation between them. How important this failure is I am unable to judge. But investigation along this line is worthy of continued effort.

ORIENTATION OF BLEBS WHERE POLYMORPHISM AND EUTECTOID RELATIONS ARE ASSUMED

Andersen⁴³ shows the thermal expansions of potash and soda feldspars, constructed on data by Kôzu and Saiki⁴⁴ for the a -, b -, and $\perp(001)$, as smooth curves, which are almost linear. I have pointed out⁴⁵ that there are small irregularities or cusps in the curves of these Japanese investigators which Anderson did not seem to recognize. Turning to Kôzu and Saiki's own data,⁴⁶ there are critical points, some of which are based upon optical behavior and others upon volumetric changes. These data point to cusps in potash rich feldspars at 900° – 950°C. and 650° – 700°C. Furthermore at 500° perthitic blebs are reported to dissolve on heating and exsolve on cooling.⁴⁷ These points may well be due to allotropic (polymorphous) changes, where the relations between the solid phases are eutectoid ones.

If this is granted for the purpose of discussion, we may ask, in what way should Andersen's arguments regarding the origin of cleavage cracks by cooling in these anisotropic materials be altered, when modifications are assumed as occurring with falling temperature? It may be that directions of such cracks may be quite different depending upon the initial temperature from which these feldspars were cooled. We do not have sufficient information to be assured that the maximum and minimum directions are the same order of magnitude for each modification. It is possible that some of the directions taken by perthitic blebs, which are seemingly not explained by Andersen's proposal, can thus be satisfactorily understood.

The rate of cooling, more especially a differential rate, with a slow decrease in temperature followed by a rapid fall, seems to me

⁴³ Andersen, Olaf, The Genesis of Some Types of Feldspar from Granite Pegmatites: *Norsk. Geologisk tidsskrift*, B. **X**, h. 1–2, 1928, p. 132, fig. 7.

⁴⁴ Kôzu, S., and Saiki, S., *Sci. Rept. Tôhoku Imp. Univ., Ser. III*, vol. **II**, No. 3, pp. 203–238, 1925.

⁴⁵ Alling, H. L., *Am. Min.*, vol. **14**, No. 6, 1929, pp. 241–242.

⁴⁶ *Op. cit.*, p. 235, Table XX.

⁴⁷ Alling, H. L., The Potash-Soda Feldspars: *Jour. Geol.*, vol. **XXXIV**, 1926, p. 602.

important if polymorphism is assumed. If the coefficients of expansion (and consequently contraction) differ from modification to modification, it is conceivable that certain cleavage planes in "unusual" directions can be thus produced. In feldspathic systems, possessing eutectoid relations, the different solid phases in transition (inversion) if they possess different solubilities, two phases would undoubtedly separate and occupy these cleavage planes. This process is one of exsolution by virtue of polymorphism and eutectoid relations. I believe we should distinguish perthites not solely on the basis of (1) simultaneous crystallization, (2) exsolution and (3) hydrothermal replacement. This is commonly done but it ignores much that is germane to the problems here. Exsolution can take place by (1) inclined solubility curves, (2) polymorphous transformations, (3) by eutectoid relations and (4) various combinations of the above. Exsolution, therefore, is a general term without a very concise meaning. When possible it seems desirable to be more specific. The nomenclature of the perthitic feldspars is discussed and tabulated later on.

DEUTERIC PERTHITES

The crystallization of an igneous rock is brought about by the solidification of a magma. It is a change in phase: liquid to solid. Such a complicated system does not suddenly become solid on fall-

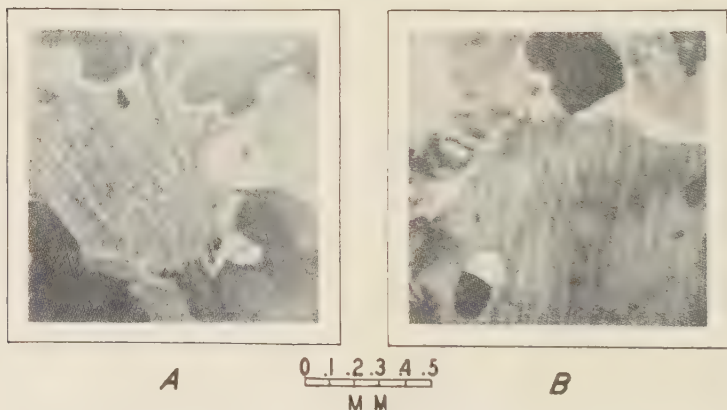


PLATE I.

Photomicrographs of deuteritic perthite, from Fort Ann, N.Y. Slide (C101) kindly loaned by R. J. Colony, illustrating his "injection perthite." Polarized light. Original magnification x66.

ing temperature, but for a considerable time consists of both crystals and liquid. It is during this "mushy" stage when under mountain-building stresses that protoclastic structures are developed. This liquid may be squeezed away from the solid crystals and be replaced by others of the same or different composition. These liquids are potentially capable of entering cleavage and cooling cracks or freezing on the margins of previously solidified crystals producing intergrowths.

Such blebs are the result of introduction from without the crystal *but not from within the system*. Many important changes in rocks are the result of late stage crystallization activity where it is perfectly conceivable that such introduced and replacing solutions were normally part of the crystallizing magma. Such processes are magmatic and not hydrothermal, yet the blebs were introduced. To such phenomena the term deuteritic can well be applied.⁴⁸

I am using the term deuteritic for those late stage magmatic changes within a *closed* system. The plutonic rocks of the Adirondack Precambrian furnish adequate examples of deuteritic feldspars. Colony⁴⁹ has photographed perthites from Fort Ann, New York, clearly showing a core of perthite coated by introduced feldspar which is apparently replacing certain blebs of the main crystal. He calls this "a sort of 'injection perthite' " and refers to the rock as a "deuterized granite." Through his kindness I have examined his slides and reproduce in Plate I photographs of my own. The evidence is quite clear that late stage activity is responsible for the blebs near the surface of the crystals. To my mind it is also clear that the perthite of the core is not deuteritic in origin but due to exsolution, in all probability due to inclined solubility curves. Hence this is a perthite of double origin, exsolution and deuteritic.

Other illustrations from the Adirondacks are shown in Plate III.

HYDROTHERMAL PERTHITES

The nomenclature of the physical chemist is applicable here and serves a very useful purpose. The term *closed system* clearly distinguishes those systems where there has been nothing added during the period of crystallization on one hand, from those referred to as

⁴⁸ Sederholm, J. J., *Bull. de la Comm. Geol. de Finlande*, No. 48, 1916.

Colony, R. I., *Jour. Geol.*, vol. XXXI, 1923, pp. 170-171.

Gillson, J. L., *Jour. Geol.*, vol. XXXVI, 1928, pp. 149-153.

Osborne, F. F., *Econ. Geol.*, vol. XXIV, 1929, pp. 335-336.

⁴⁹ Colony, R. J., *Jour. Geol.*, vol. XXXI, 1923, pp. 170-171, fig. 1.

open system where material from the outside has been introduced on the other. So far we have discussed those perthites which are closed systems. In dealing with hydrothermal action we pass to those systems which are open. Such introduced solutions can fill cleavage and cooling cracks and on freezing produce intergrowths. Furthermore, such solutions may replace in whole or in part a feldspathic original and hence replacement perthites are produced.

Economic geologists, who are students of metalliferous deposits, have of recent years emphasized replacement as the cause of many intergrowths, particularly of sulphide minerals and frequently refer to them as possessing a "pseudo-eutectic texture." Lindgren⁵⁰ has recently expressed his opinion with references to the literature and illustrates his paper with beautiful photomicrographs showing intergrowths of tennantite, $\text{Cu}_6\text{As}_2\text{S}_6$, and stromeyerite, $(\text{Cu}, \text{Ag})_2\text{S}$, sphalerite and galena, sphalerite and chalcopyrite. I could give many other references such as to Whitehead,⁵¹ Rogers,⁵² etc., but these will suffice to make my point: intergrowths in rocks and ores which exhibit perthitic or eutectic textures are by no means the product of the same process. The problem is fundamentally a psychological one. Metallographers observe true eutectic textures in metallic alloys definitely the result of simultaneous solidification of a melt. Then all eutectic textures are eutectics? Certainly not! The economic geologist, studying polished specimens of ore minerals under the reflecting microscope, finds "pseudo-eutectic" textures. Are *all* such textures due to replacement? In all honesty he must reply "no," but conscientiously he holds that certain ones, or the great majority of them even, are due to replacement. Why this difference in conclusions between the metallographers on one hand and the economic geologists on the other? Because essentially one is dealing with closed systems and the other with open systems. The former are systems whose fluidity is due to heat; the latter due to a solvent.

The petrologist studies phenomena covering both ranges. Perthites occur in plutonic, hypabyssal and volcanic rocks and in many secondary products derived therefrom. I therefore insist that perthites must have many origins. There are perthites and perthites.

What conclusions are reached when a student of ore deposits

⁵⁰ Lindgren, Waldemar, *Econ. Geol.*, vol. XXV, 1930, pp. 1-13.

⁵¹ Whitehead, W. L., *Econ. Geol.*, vol. XI, 1916, pp. 1-13.

⁵² Rogers, A. F., *Econ. Geol.*, vol. XI, 1916, pp. 582-593.

studies perthite from a pegmatite knob? Hydrothermal replacement, of course.⁵³ And it may be in whole or in part. When a petrographer investigates the evolution of plutonic rocks and finds perthite, and concludes that exsolution would account for it, are we surprised at his opinion? Not at all.

Many illustrations are available which can be called into court as evidence for the introductions of feldspar materials from without. Many pegmatitic microclines show irregular patches of plagioclase apparently without orientation of any kind. These are common and called "secondary."⁵⁴

BLEBS INFLUENCED BY INCLUSIONS IN ADIRONDACK PERTHITES

Microscopic studies of Adirondack syenite-granites show inclusions of quartz and soda-bearing pyroxenes in perthites. It is at once seen that there are two generations of blebs in these perthites. one set is in the form of round or elliptical rods which Andersen calls "string" perthite, which is an early development and is assigned both by Andersen and myself to exsolution. The other set

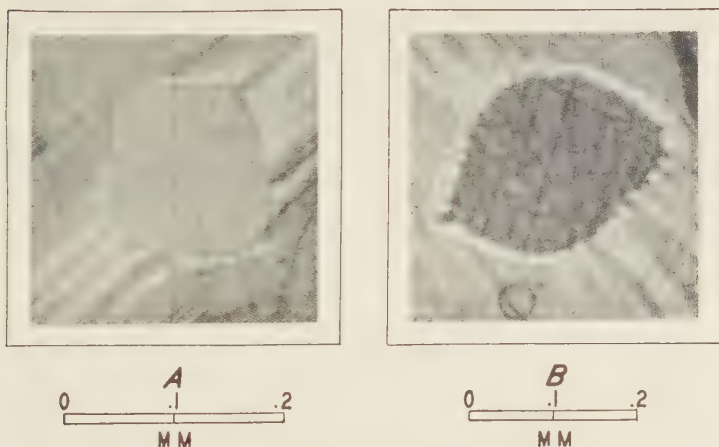


PLATE II.

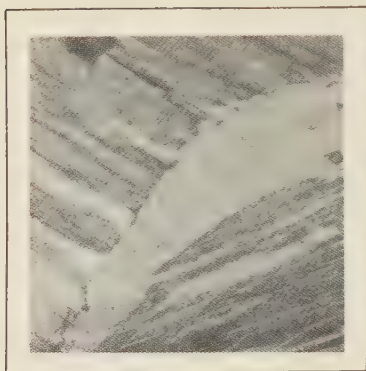
Photomicrographs of composite perthite influenced by inclusions. Syenite-granite, Ausable Forks, Ausable quadrangle, Adirondack Mountains. Polarized light. Slide 1087c.

A. Inclusion of quartz. Original magnification x285.

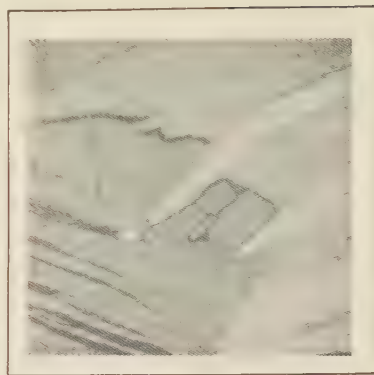
B. Inclusion of aegirite-augite. Original magnification x224.

⁵³ See Megathlin, G. R., The Pegmatite Dikes of the Gilsum Area, N.H.: *Econ. Geol.*, vol. XXIV, 1929.

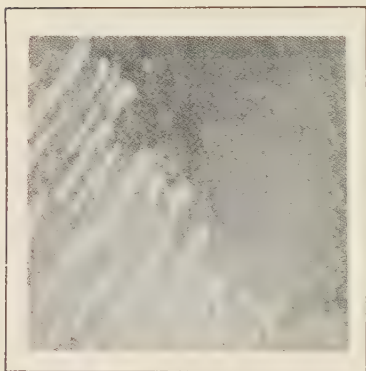
⁵⁴ Harker, Alfred, The Natural History of Igneous Rocks, 1909, p. 259.



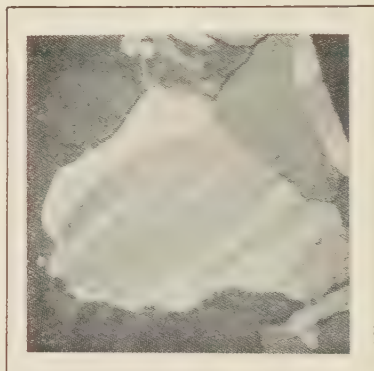
A 0 .1 .2 .3



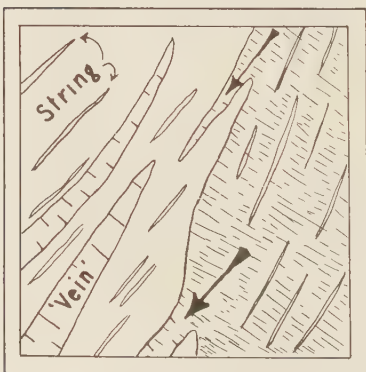
B 0 .1 .2



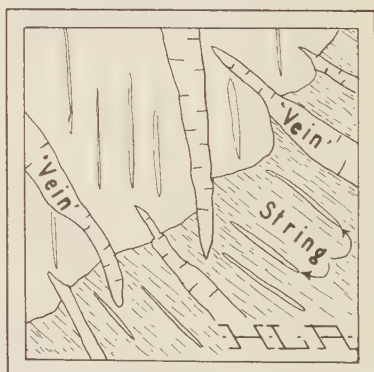
C 0 .1 .2 .3



D 0 .1 .2 .3 .4 .5



E 0 .05 .1



F 0 .05 .1

PLATE III

Photomicrographs and drawings of various composite perthites from the Adirondacks.

A. String and "vein" penetrating perthite in syenite-granite (quartz nordmarkite), Ausable Forks, N.Y. Polarized light. Original magnification x118. Slide 1087c.

B. String and "vein" penetrating perthite in syenite-granite (quartz nordmarkite), Ausable Forks, N.Y. Polarized light. Original magnification x160. Slide 61.

C. Composite perthite in granite, three-quarter mile south southwest of Little River. Canton Quadrangle. Polarized light. Original magnification x143. Slide 1948.

D. Deuteric perthite in syenite-granite (quartz nordmarkite) Ausable Forks, N.Y. Polarized light. Original magnification x80. Slide 61'.

E. Camera lucida drawing of composite penetrating perthite in syenite-granite (quartz nordmarkite), Ausable Forks, N.Y. Original magnification x 450. Slide 1087c. The arrows point to penetrating blebs.

F. Composite camera lucida drawing of composite interpenetrating perthite in syenite-granite from several slides from Ausable Forks and the Saranac Lake Quadrangle. Original magnification x 400.

consists of albite-rich blebs much more irregular in shape and in orientation which are later in development. These masses appear to be identical to, or very similar to what Andersen calls "vein" perthite.

The position of the "vein" type of bleb is greatly modified by the presence of these inclusions as can readily be seen from Plate II. The "vein" albite-rich feldspar appears to have been pushed aside by the inclusions. This feldspar is more or less completely coating the margins of the inclusions and yet it is strongly influenced by the cooling cracks and roughly parallel to the directions taken by the exsolution "string" type of blebs.

I suggest that the differential rates of contractions of the host feldspar and the inclusions have produced strains along the contact, producing channelways for the solutions that were responsible for the "vein" type of feldspar, and yet I feel that this phenomenon is not hydrothermal but deuteric in origin.

PENETRATING PERTHITES

Slides of Adirondack granitic rocks from many localities show that the contacts between perthite grains are decidedly undulatory by large irregular blebs of one grain penetrating another. Plate III illustrates this phenomenon. In certain slides there is a mutual penetration and hence albitic blebs interpenetrate each other. The penetrating blebs have the appearance of the "vein" type of Ander-

sen. They certainly belong to a second generation⁵⁵ of blebs. Andersen's "vein" type is found in pegmatites. This type of bleb he regards as due to "circulating solutions derived from the same pegmatite magma from which the initial crystallization of the feldspar took place."⁵⁶ I believe I am correct in interpreting this statement to mean a closed system and hence I believe these "vein" blebs are deuteric. However, Andersen's "interlocking perthite" as seen in his beautiful photomicrographs⁵⁷ does not have the appearance of the type I have in the Adirondack plutonic rocks, and hence the theory of simultaneous crystallization is thought not to apply to these.

THE CLASSIFICATION OF PERTHITES

I have been maintaining for some years now, that there is no single origin for perthite. Rather that there are many possible causes of these intergrown feldspars. Recent publications have emphasized this growing opinion. Andersen, after carefully studying, listing, and photographing many textural relations exhibited by pegmatitic perthites, states that there is "conclusive evidence for the assertion that the perthites have been formed as a result of *several* (my italics) processes."⁵⁸

He proceeds to recognize a number of textural types to which he assigns appropriate origins, as follows:

(1) *String Type of Perthitic Bleb*. These are relatively long round or elliptical rods of soda-rich feldspar in a potash-rich host. They usually lie parallel to (010). This type, Andersen believes, is due to "exsolution in the solid state at an early stage in the evolution of the feldspar."⁵⁹

(2) *Film Type of Perthitic Bleb*. These soda-rich feldspar blebs occur as thin films perpendicular to (010), and at an angle of about 73° to (001), and are larger than the string type. Andersen assigns this to "exsolution but probably at a later stage (lower temperature) than string perthite."⁶⁰

(3) *"Vein" Type of Perthitic Bleb*. These are very common in pegmatites and relatively large in size, rather irregular in shape,

⁵⁵ Alling, H. L., *Jour. Geol.*, vol. XXXIV, 1926, p. 610.

⁵⁶ Andersen, Olaf, *Norsk. Geologisk tidsskrift*, B, X, h. 1-2, 1928, p. 150.

⁵⁷ *Op. cit.*, Pl. VII, 2A, 2B, and 3.

⁵⁸ Andersen, Olaf, *Norsk. Geologisk tidsskrift*, B, X, h. 1-2, 1928, p. 163.

⁵⁹ *Op. cit.*, p. 149.

⁶⁰ *Op. cit.*, p. 150.

though usually lens shaped. Generally they are roughly parallel to the (100) face but are noted as running through the host feldspar without much relation to crystallographic directions. These Andersen considers due to solutions derived from the pegmatitic magma filling contraction cracks. My experience with feldspars, with this type of bleb in pegmatites, leaves me in doubt whether they are deuteric or hydrothermal in origin. I don't know whether my experience has been too limited or too extensive to allow me to reach a decision. I am willing at the present time to suggest that "vein" perthite in pegmatites is the result of lower temperature conditions than is the case of similar blebs in perthites in plutonic rocks. Hence pegmatitic "vein" blebs may be on the boundary between deuteric and hydrothermal, while plutonic "vein" blebs are deuteric.

(4) *Patch Type of Perthitic Bleb.* By this term Andersen recognizes a transitional type: "vein" type grading into "pure" albite. The patches of albite are noticeable elongated in the direction of the *b*-axis. He states that this type of perthite is commonly supposed to be the product of replacement. Here I would suggest that the "pure" albite represents still lower temperatures.

It may be that the term "pure albite" is perhaps a little misleading, in that its composition may not be one hundred percent $\text{NaAlSi}_3\text{O}_8$. I suppose what Andersen desires to convey is that it appears to be homogeneous and is not a two phase system.

In Fig. 2. I have attempted a classification based upon a thermal scale, ranging from high (magmatic) temperatures to low temperatures. I recognize closed and open systems⁶¹ and the difficulty of always clearly distinguishing them. Many readers may not accept the terms used in column 3, questioning with Ross⁶² the wisdom of employing the word "magmatic" as too inclusive. Likewise "deuteric" is none too definite in meaning. "Pneumatolytic," implying gas-controlled processes, has been so attenuated that it has "lost all definite meaning"⁶³ and so on. Nevertheless, they have proved useful in class and may be here as well.

Andersen's terms are used in column 4. The only change I have made was in the placing of quotation marks around the term "vein" as applied to a type of perthitic bleb, as the word is likely to be confused with low temperature vein conditions as is used in column 3.

⁶¹ See Schaller, W. T., *Am. Min.*, vol. **XII**, 1927, p. 59.

⁶² Ross, C. S., *Econ. Geol.*, vol. **XXIII**, 1928, p. 867.

⁶³ *Op. cit.*

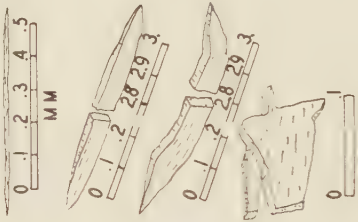


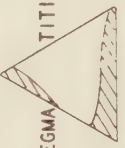

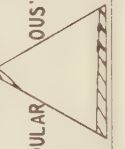
1	2	3	4	5	6	7
TEMPERATURE	SYSTEM	CONDITION	TYPE OF BLEB	SHAPE AND SIZE OF BLEBS	COMPOSITIONAL RANGE	TYPE OF FELDSPAR
HIGH	CLOSED	MAGMATIC	STRING FILM "VEIN"		 K-F PORPHY RITIC	SANIDINE BARBIERITE
					 Na-F PLU TONIC	ORTHOCLASE ALBITE
					 PEGMA TITIC	MICROCLINE ANALBITE
INTER-MEDIATE	OPEN	PNEUMATO-LYTIC HYDRO-THERMAL	PATCH	 DRU SY		
					 "ADULAR OUS"	ADULARIA CLEAVELANDITE
LOW			PLATY			HLA

FIG. 2. A Classification Chart of Various Perthites. Compiled from a number of sources.

Column 2. The terms are those used by Schaller.^a

^a Schaller, W. T., *Am. Min.*, vol. **XII**, 1927, p. 59.

Column 3. The terms are useful even though not without objections.^b

^b Ross, C. S., *Econ. Geol.*, vol. **XXIII**, 1928, p. 867.

Column 4, gives the names used by Andersen.^c

^c Andersen, Olaf, *Norsk. Geologisk tidsskrift*, B. **X**, h. 1-2, 1928, p. 163.

Column 5 shows conventionalized drawings of size and shape of perthitic blebs, the data taken from Andersen.

Column 6. The composition ranges were taken from diagrams of Mäkinen.^d

^d Mäkinen, E., *Geol. Fören. Förhandl.*, vol. **XXXIX**, 1917, pp. 121-184.

Column 7. The names I have used as modified from Winchell^e and Andersen.

^e Winchell, A. N., *Jour. Geol.*, vol. **XXXIII**, 1925, p. 719. Elements of Optical Mineralogy, Part II, Wiley and Sons, 1929, pp. 316-7.

Alling, H. L., *Jour. Geol.*, vol. **XXXIV**, 1926, p. 593.

The sizes and shapes of the blebs have been conventionalized as the variety in these is seemingly unlimited and I desired to simplify the diagram as much as possible.

The compositional ranges and terms are patterned after Mäkinen's diagrams.⁶⁴ Normal feldspars are confined to the lined areas, compositions consisting of a single phase. According to the diagrams, homogeneous anorthoclasic feldspars are possible in porphyritic and plutonic feldspars but not in lower temperature diagrams. The term "adularious" is an adjective coined from adularia. Here I depart from Winchell⁶⁵ and regard adularia as hydrothermal in origin or as a product of vein formation. Tolman⁶⁶ has discussed the presence of feldspars in quartz dikes and concludes that "under . . . low temperatures are formed the purest feldspars: adularia, with little Ab⁶⁷ (+An), and plagioclase with no K-feldspar. They constitute the feldspars normally found in veins." Also that "perthite is not an orthodox vein forming mineral."⁶⁸ It can be observed that the white areas in Mäkinen's diagrams, denoting two phase conditions, increase with falling temperatures. To place "adularia" where "orthoclase" is printed, as Winchell has done, interrupts the nicety of the scheme.

⁶⁴ Mäkinen, E., *Geol. Fören. Förhandl.*, vol. **XXXIX**, 1917, pp. 121-184.

⁶⁵ Winchell, A. N., *Jour. Geol.*, vol. **XXXIII**, 1925, p. 719. Elements of Optical Mineralogy, Pt. II, Wiley and Sons, 1929, pp. 316-317.

See Alling, H. L., *Jour. Geol.*, vol. **XXXIV**, 1926, p. 593.

⁶⁶ Tolman, Carl, *Am. Min.*, vol. **XVI**, 1931, p. 296.

⁶⁷ Na-Feld. would be noncommittal regarding the exact modification co-existing with adularia.

⁶⁸ *Op. cit.*, p. 297.

In the last column I have shown the names I have used for trimorphous modifications of both components. The placing of cleavelandite with adularia was, I admit, an inspiration, but it may be subject to criticism.

Horizontal lines have not been drawn across the chart. I do not wish to lose sight of the gradational, transitional characters intended in spite of the apparent definiteness of the diagram.

TABLE III
TERMINOLOGY OF THE PERTHITES

Process	Name
Eutectic. Simultaneous crystallization.	1. Eutectic Perthite. (Are there any?)
Loss in solubility by change in modification. Sanidine-barbierite to orthoclase-albite. That is, from gamma feldspars to beta.	2. Gamma→beta Perthite.
Eutectoid on change in modification. Sanidine-barbierite to orthoclase-albite. That is, from gamma feldspars to beta.	3. Gamma→beta Perthoid ⁶⁹
Loss in solubility in change in modification. Orthoclase-albite to microcline-analbite. That is, from beta feldspars to alpha.	4. Beta→alpha perthite.
Eutectoid on change in modification. From orthoclase-albite to microcline-analbite. That is, from beta feldspars to alpha.	5. Beta→alpha perthoid ⁶⁹
Loss in solubility due to inclined solubility lines.	6. Exsolution perthite.
Deuteric, closed system	7. Deuteric perthite.
Pneumatolytic	8. Pneumatolytic perthite.
Hydrothermal	9. Hydrothermal perthite
Replacement	10. Replacement perthite
Composite	11. Composite perthite

⁶⁹ Alling, H. L., *Jour. Geol.*, vol. **XXIX**, 1921, p. 224. "There would be a gain for clearness if . . . 'perthoid' [could be used] to refer to intergrowths of potash-soda feldspars due to [certain types of] exsolution."

THE TERMINOLOGY OF PERTHITES

It would simplify matters if the term "perthite" should be limited to a textural meaning. Then generic terms could be used in connection with, or hyphenated to, it. With this as a basis I have drawn up Table III, in the hope that it may assist others. If the nomenclature is too ponderous, as it may be, I believe that the ideas there implied are of value nevertheless.

It is believed that the processes listed above overlap and consequently many perthites are composite in order. I have seen perthites where the string type of blebs were probably due to those processes numbered 2 and 3, while the film type of blebs represent those numbered 4, 5, and 6, and also "vein" blebs produced from those numbered 7 and 8. These would be listed as composite perthites.

X-RAY EXAMINATIONS OF CHROME ORES: (I) LATTICE DIMENSIONS; (II) THEORETICAL DENSITIES

G. L. CLARK AND ABDE ALLY, *University of Illinois.*

(I) LATTICE DIMENSIONS

As a part of an investigation of certain properties of chrome ores, the lattice dimensions of five chromites from various localities ranging in composition from 33% to 53% Cr_2O_3 were determined.

The diffraction patterns were obtained using a multiple unit apparatus, made by the General Electric Company. The radiations employed were $\text{K}\alpha$ doublet of molybdenum of the wave length 0.712 Å.U. The spacings were standardized with sodium chloride.

The length of the edge of the unit cube a_0 for the five ores, given in the table II is calculated from the two following equations of x-ray spectroscopy^{1,2}

$$\frac{d}{n} = \frac{\lambda}{2 \sin \theta} \quad (1)$$

$$a_0 = \frac{d_{hkl}}{n} \sqrt{(h^2 + k^2 + l^2)n^2} \quad (2)$$

d/n , the spacing measurements of the diffraction lines, recorded in the third column of the table II are for the chrome ore A. In the fourth column are given the estimated relative intensities for the same ore, assigning the brightest line a value of ten.

In the cubic system the ratios of $\sin^2 \theta$, (the latter being computed from the equation I) should give values which are integers and usually small. These values given in column five for A alone, diverge within the limits of the experimental error from the corresponding whole numbers given in the second column of the table II. The whole numbers represent the sum of $(h^2 + k^2 + l^2)n^2$ and aid in assigning the indices of the planes producing the diffraction pattern.

The ores examined were:

- A. Rhodesian African lump chrome ore
- B. Transvaal African lump chrome ore
- C. Grecian lump chrome ore
- D. Cuban lump chrome ore
- E. A high grade chrome ore, locality not known.

The ores for which no analyses were supplied were analyzed. In the case of the ores for which only partial (factory) analyses were available, the undetermined constituents were estimated in order to note roughly any obvious relationship existing between the lattice dimension and the chemical composition. The estimates were based upon the analyses of the typical ores found in the localities whence the ores were obtained. Publications on the mineral resources of U.S.³ and the records of the Geological Surveys were consulted in this connection. Two of the typical analyses of the Rhodesian and Grecian ores given by McDowell⁴ are:

	Rhodesian	Grecian
Cr ₂ O ₃	48.4	39.5
FeO	14.4	15.8
Al ₂ O ₃	12.1	26.2
MgO	14.2	15.8
SiO ₂	5.9	3.0
CaO	—	—

The estimates of the undetermined oxides of the Rhodesian (A) and Grecian (D) ores were partly based upon these. For Transvaal ore the estimates were based upon Wagner's⁵ work. Parantheses are placed around the figures which are estimated. The analyses of the ores are given in the table I.

TABLE I
ANALYSES OF THE CHROME ORES

	A Rhodesian	B Transvaal	C Cuban	D Grecian	E	Hungarian (Todoky ¹⁰)
Cr ₂ O ₃	47.14	42.68	33.83	37.74	53.08	54.22
SiO ₂	7.75	3.34	3.11	6.09	5.11	6.16
FeO	(15.00)	(27.00)	13.07	(15.00)	14.00	25.94
CaO			Trace		2.59	
MgO	(15.00)	(10.00)	17.61	(15.00)	8.95	9.77
Al ₂ O ₃	(13.00)	(15.00)	31.11	(26.00)	16.11	2.29
Loss on Ignition			1.12			
MnO						0.94
TiO ₂						0.68
H ₂ O						0.09
Total	97.89	98.02	99.85	99.83	99.84	100.09

The results seem to indicate that the values of a_0 for the different ores are inversely proportional to the Al_2O_3 content; or the higher the amount of aluminates present in the isomorphous mixture of spinels, the lower is the length of the edge of the unit cube (See Fig. 1).

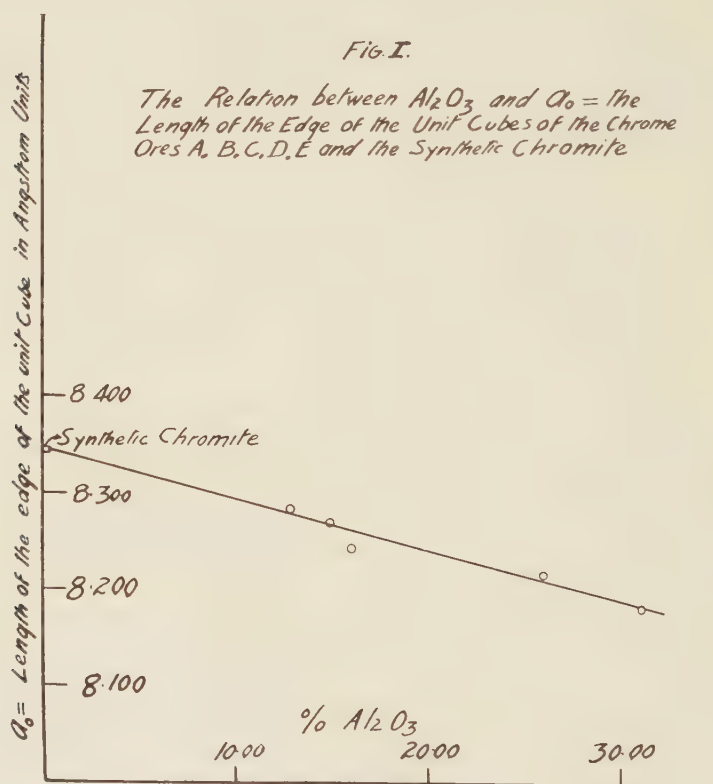


FIG. 1

Tests on synthetic spinels⁶ had shown that the structures of the chromites of Zn, Mg, Fe and Mn are generally intermediate between the structures of their ferrites and their aluminates. The lattice dimensions of the aluminates ranged from 8.062 to 8.271 Å.U.; those of the chromites varied from 8.296 to 8.436, the ferrites had the values between the limits of 8.423 to 8.457. Therefore, when either Al_2O_3 or Fe_2O_3 replaces Cr_2O_3 from the chromite molecule the value of a_0 should be lowered or raised in proportion to the replacement, in accordance with the additive law of Vegard.⁷

TABLE II
POWDER DIFFRACTION DATA FROM CHROME ORES

Indices	$(h^2 + k^2 + l^2)a^2$	$\frac{d}{n}$	Estimated Intensity	Ratios of $\sin^2 \theta$	a_0 Chrome Ore A	a_0 Chrome Ore B	a_0 Chrome Ore C	a_0 Chrome Ore D	a_0 Chrome Ore E
111 (1)	3	4.80	5	2.98	8.31	8.29	8.19	8.23	8.24
110 (2)	8	2.93	6	79.90	8.28	8.28	8.17	8.23	8.25
113 (1)	11	2.499	10	11.00	8.29	8.26	8.19	8.21	8.23
111 (2)	12	2.390	v.f.	12.03	8.28	8.28	v.f.	v.f.	8.24
100 (4)	16	2.070	7	15.99	8.28	8.27	8.16	8.20	8.24
112 (2)	24	1.690	4	24.00	8.28	8.26	8.18	8.20	8.23
111 (3)	27	1.592	9	27.05	8.28	8.26	8.18	8.22	8.23
115 (1)									
110 (4)	32	1.461	9	32.14	8.27	8.27	8.18	8.22	8.26
135 (1)	35	1.398	v.f.	35.00	8.28	8.26	8.17	8.22	8.24
130 (2)	40	1.310	2	39.95	8.29	8.26	8.18	8.23	8.24
335 (1)	43	1.261	5	43.11	8.27	8.27	8.19	8.22	8.25
111 (4)	48	1.196	3	47.95	8.29	8.26	8.18	8.21	8.24
155 (1)	51	1.158	2	51.01	8.27	8.27	8.19	8.21	8.25
117 (1)									
123 (2)	56	1.107	3	55.90	8.29	8.26	8.16	8.23	8.24
355 (1)	59	1.079	6	58.91	8.28	8.27	8.18	8.22	8.23
137 (1)									
100 (8)	64	1.035	3	64.00	8.28	8.26	8.17	8.22	8.24
110 (6)	72	0.975	2	72.15	8.28	8.26	8.17	8.22	8.24
114 (2)									
111 (5)	75	0.956	4	75.01	8.28	8.26	8.17	8.20	8.24
157 (1)									
120 (4)	80	0.927	3	79.80	8.29	8.27	8.19	8.22	8.23
139 (1)	91	0.869	3	90.82	8.29	8.28	8.19	8.21	8.24
112 (4)	96	0.846	6	95.89	8.29	8.27	8.17	8.22	8.24
134 (2)	104	0.811	1	104.30	8.27	8.25	8.19	8.22	8.24
150 (2)									
159 (1)	107	0.801	4	106.89	8.28	8.27	8.17	8.21	8.24
377 (1)									
					8.283 ± 0.001	8.267 ± 0.001	8.179 ± 0.002	8.216 ± 0.001	8.241 ± 0.001

TABLE III

Synthetic Chromite ⁸	Rhodesian A	Transvaal B	E	Grecian D	Cuban C	Ural ⁹	Hungarian ¹⁰
8.344 ± 0.003	8.283 ± 0.001	8.267 ± 0.001	8.241 ± 0.001	8.216 ± 0.001	8.179 ± 0.002	8.355 ± 0.004 ; 8.358 ± 0.004	8.05

In this investigation it appears that Cr_2O_3 is replaced by Al_2O_3 alone since the values of a_0 gradually decline from the synthetic FeCr_2O_4 , which contains no Al_2O_3 to the Cuban ore which contains 31% Al_2O_3 . This seems to be further substantiated by the fact that the 5 ores examined are nonmagnetic while all the known ferrites, except ZnFe_2O_4 , are ferromagnetic and zinc seldom occurs in chromite.^{8,12}

It may be inferred that iron which is generally analyzed as Fe_2O_3 is present in these ores wholly in ferrous form (ferrous chromite, FeC_2O_4 ; ferrous aluminate, FeAl_2O_4) and not as ferrite.

No characteristic diffraction lines were observed for the minerals of SiO_2 and CaO , although they are not minerals of the spinel series. Their presence in the isomorphous spinel molecule whether interstitial or substitutional does not seem to have any marked effect on the lattice constants.

The x -ray data obtained by other investigators on chrome ores are given in the table III, together with those obtained in this investigation. Todoky's value of 8.05 Å.U. appears to be low considering the fact that it is a high grade chrome ore as revealed by its analysis (see Table I)

The quality of the chrome ore, it is evident, can not be definitely ascertained by means of x -ray examination; however, it can be roughly surmised as to its Al_2O_3 content.

(II) THEORETICAL DENSITIES

An attempt was made to compute the theoretical densities of the ores by employing the well known relation:

$$\rho = \frac{nM}{a_0^3}$$

in which ρ = density

n = number of molecules per unit cell;
8 in the case of spinels

M = molecular weight of the substance

a_0 = length of the edge of the unit cube.

The above equality holds true in the case of a substance composed only of a single kind of crystal. The ore is regarded as such, consisting of an isomorphous mixture of spinels.

The small amount of the mineral impurities in the ore (possibly due to the improper separation of chromite from gangue), some of these being visible under the microscope, yet giving no evidence of their presence in the diffraction patterns, were regarded, in order to

simplify the "average molecular weight" (M) computations, as being present within the chromiferous spinelled in solid solution. The value for M was determined from the mineral analysis of the ore. The following rules were observed in calculating the latter.

1. All Cr_2O_3 or FeO was regarded as entering the chromite molecule.
2. SiO_2 was disposed of as magnesium olivine— $2\text{MgO} \cdot \text{SiO}_2$; serpentine— $2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2$; or as uvarovite— $3\text{CaO} \cdot \text{Cr}_2\text{O}_3 \cdot 3\text{SiO}_2$; microscopic study determining the choice.
3. The remaining oxides were distributed to form the other members of the spinel series— $\text{MgO} \cdot \text{Cr}_2\text{O}_3$, $\text{MgO} \cdot \text{Al}_2\text{O}_3$, $\text{FeO} \cdot \text{Al}_2\text{O}_3$. The excess of either acidic or basic oxides, which practically all chrome ore analyses indicate, were reported as such—periclase (MgO) and corundum (Al_2O_3).
4. Ignition loss reported in the Cuban ore, C, was regarded as CO_2 and was disposed of as magnesite, MgCO_3 .

Taking, as an illustration, chrome ore C, for which a complete analysis was available, the percentages of the various oxides were divided by their molecular weights, and these were later combined to form different minerals, as is illustrated below.

$$\text{Mols. of various oxides} = \frac{\text{Percentage}}{\text{Molecular Weight}}$$

	Cr_2O_3 0.2225	FeO 0.1821	SiO_2 0.0513	MgO 0.4371	Al_2O_3 0.3045	CO_2 (Ignition loss) 0.0254
0.1821 $\text{FeO} \cdot \text{Cr}_2\text{O}_3$	0.1821	0.1821				
0.0513 $2\text{MgO} \cdot \text{SiO}_2$			0.0513	0.1026		
Magnesium olivine						
0.0404 $\text{MgO} \cdot \text{Cr}_2\text{O}_3$	0.0404			0.0404		
0.0254 MgCO_3				0.0254		0.0254
Magnesite						
0.2686 $\text{MgO} \cdot \text{Al}_2\text{O}_3$				0.2686	0.2686	
spinel						
0.0359 Al_2O_3					0.0359	
Corundum						
0.6037 Total						

0.6037 is the combined mols. of different minerals present in 100 gms. of the ore. Therefore, the average molecular weight of the ore is $100/0.6037 = 165.6 = M$, and the density

$$\rho = \frac{8 \times 165.6 \times 1.649 \times 10^{-24}}{(8.179 \times 10^{-8})^3} = 3.989.$$

The mineral analyses, theoretical densities, and the true specific gravities of the chrome ores and the per cent difference between the theoretical and the actual values are given in the Table III.

It should be noted that the combined mols. of different minerals in each ore were uniformly divided into 100, to obtain the average molecular weight of the ore, regardless of the fact that the analyses slightly deviated from this sum.

In the case of A, in order to form 0.0646 mols. of serpentine, the presence of which was confirmed by microscopic examination of the ore, 2.33% H_2O is necessary. This is not provided for in the analysis for A (Table) where only the three main unanalyzed constituents were estimated. However, when 2.33% H_2O is added to 97.89% already accounted for the sum approaches about 100%, which, as mentioned above, was used in the average molecular weight calculation.

The sum of analyzed and unanalyzed oxides totaled 98.02% in the case of B (See table I); the total number of mols. of different minerals was slightly smaller and the theoretical density and the "average molecular weight" were a little larger due to the fact that 100 was used as the basis instead of the actual value of 98.02%. In this particular case the deviation between the theoretical and the actual densities was found to be the maximum, 5.93%.

This method of computing the theoretical density of the ore by calculating an "average molecular weight" from the chemical composition should be applicable to all substances¹¹ forming continuous solid solutions and obeying the additive law of Vegard.

SUMMARY

Diffraction data by the "powder method" were obtained from 5 chrome ores found in various localities. The length of the edge of the unit cube ranged from 8.283 ± 0.001 to 8.179 ± 0.002 , varying inversely with the Al_2O_3 content of the ore.

A method which has been applied to alloys for computing the theoretical density has been extended for calculating the "average molecular weight" of the chrome ore; this method is generally applicable to substances, forming isomorphous mixtures and continuous substitutional solid solutions which obey the additive law of Vegard. The theoretical densities of the 5 ores obtained by this method had a maximum difference of 1.3% between the theoretical and the actual values in the case of ores with complete analyses

TABLE III
THE MINERAL ANALYSES, THEORETICAL DENSITIES, AND THE TRUE SPECIFIC GRAVITIES OF THE CHROME ORES

	A	B	C	D	E	Synthetic
	Rhodesian	Transvaal	Cuban	Grecian		Chromite
$\text{FeO} \cdot \text{Cr}_2\text{O}_3$ (Chromite).....	0.2089	0.2808	0.1821	0.2090	0.1951	
$\text{MgO} \cdot \text{Cr}_2\text{O}_3$ (Magnochromite).....	0.1012		0.0404	0.0391	0.1384	
$\text{MgO} \cdot \text{Al}_2\text{O}_3$ (Spinel).....	0.0772	0.0515	0.2686	0.2421	0.0065	
$2\text{MgO} \cdot \text{SiO}_2$ (Magnesium olivine)....		0.0554	0.0513	0.1010	.0386	
$2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2$ (Serpentine)....						
$3\text{CaO} \cdot \text{Cr}_2\text{O}_3 \cdot 3\text{SiO}_2$ (Uvarovite)....	0.0646				0.0154	
MgCO_3 (Magnesite).....		0.0857	0.0254			
MgO (Periclase).....						
Al_2O_3 (Corundum).....	0.0500	0.0952	0.0359	0.0133	0.1511	
$\text{FeO} \cdot \text{Al}_2\text{O}_3$ (Hercynite).....						
Total No. of Mols. in 100 gms. of the ore.....	0.5019	0.5686	0.6037	0.6045	0.5451	
Average Molecular Weight.....	199.1	175.8	165.6	165.3	183.3	
Theoretical Density.....	4.619	4.145	3.989	3.934	4.245	5.085
True Specific Gravity D_{20}^{20}	4.421	3.913	3.980	3.888	4.191	4.998
Difference between theoretical and actual densities in per cent.	4.79%	5.93%	0.226%	1.18%	1.29%	1.74%

available, and a maximum difference of 5.93% where some of the undetermined constituents were estimated.

ACKNOWLEDGMENTS

Acknowledgments are due Messrs. A. E. Badger and A. J. Monack of the Department of Ceramic Engineering at the University of Illinois for valuable suggestions; Mr. J. E. Lamar of the Illinois State Geological Survey for the optical studies; and Mr. J. S. McDowell of the Harbison Walker Refractories Company for furnishing four of the five ores investigated.

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CREEDITE FROM NEVADA

WILLIAM F. FOSHAG,¹ *United States National Museum.*

The mineral creedite was first found by Esper S. Larsen in the fluorite mines of Wagon Wheel Gap, Creede Quadrangle, Colorado, and described by Larsen² and Wells as a new mineral species of the composition $\text{CaSO}_4 \cdot 2\text{CaF}_2 \cdot 2\text{Al}(\text{F},\text{OH})_3 \cdot 2\text{H}_2\text{O}$. Later, better material was obtained and the mineral further investigated by the present writer³ confirming the composition as found by Wells and determining the crystal symmetry and elements. The mineral was found to be monoclinic. Several crystal habits were found, all prismatic but differing somewhat in the relative sizes of the terminal faces. The mineral is associated with fluorite or embedded in a white halloysite clay.

During geological field work for the U. S. Geological Survey in the Tonopah Quadrangle, Nevada, Mr. Stanley H. Cathcart visited the small gold camp of Granite (now abandoned), northwest of Tonopah in the northwestern corner of the Tonopah quadrangle and collected some specimens of the high grade ore found in the small veins of the district. These specimens showed scattered bunches of a colorless prismatic mineral which were determined by Dr. Clarence S. Ross, from their optical properties, to be creedite. The specimens were then turned over to the present writer for further study and are now in the collections of the U. S. National Museum (No. 96489).

The two specimens suggest that the gold bearing deposits of Granite are fluorite-quartz veins with free gold. The specimens are from the oxidized zone and are discolored by a clayey manganese wad. Visible flakes of gold are embedded both in the wad and in the fluorite. The fluorite is pale green in color where fresh surfaces are exposed. There are also small seams of a white to discolored gray halloysitic clay.

The creedite is in the form of small needles, usually less than 2 millimeters in length. On one specimen it forms a crust of reticulated needles; on the other, found lining cavities, as drusy wart-like

¹ Published by permission of the Secretary of the Smithsonian Institution.

² Esper S. Larsen and Roger C. Wells: *Jour. Wash. Acad. Sci.*, vol. 2, pp. 360-365, 1916.

³ W. F. Foshag: *Proc. U. S. Nat. Museum*, 59, pp. 419-424, 1921.

masses, as radiated aggregates resembling wavellite in structure or as needles embedded in clay. The crystals are colorless or stained a pale buff to pink color, are glassy in luster and some crystals show a faint opalescence similar to many of the crystals from Creede.

The crystals were well formed but examination on the goniometer show the faces to be somewhat curved so that crystal measurements were not entirely satisfactory. Eight forms were noted, two of them not found on the Creede material and are therefore new for this mineral. The measurements are given in the following table.

MEASUREMENT OF CREEDITE FROM NEVADA

Face	Found		Calculated	
	ϕ	ρ	ϕ	ρ
$m(110)$	31°40'	90°00'	31°45'	90°00'
$a(100)$	90 00	90 00	90 00	90 00
$c(001)$	90 00	5 38	90 00	4 30
$p(111)$	35 11	54 49	34 30	54 36
$n(\bar{1}11)$	29 26	-53 1	28 52	-52 56
$d(101)$	90 00	38 43	90 00	38 33
$i(\bar{1}01)$	90 00	-32 32	90 00	-32 35
$v(331)$	37 38	31 30	38 4	30 33

The new orthodome $d(101)$ was noted as a small modifying face on crystals with a prominent base. The new pyramid $v(331)$ is likewise a narrow modifying face between the unit pyramid and the prominent base. Both forms were noted several times and

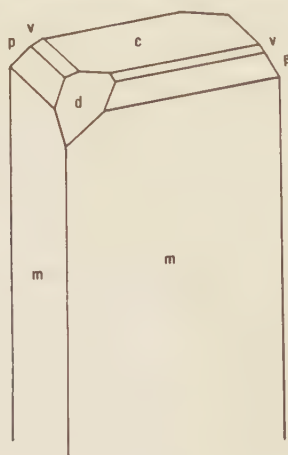


FIG. 1. Crystal of Creedite from Granite, Nevada, showing the new forms $d(101)$ and $v(331)$.

while the reflections were not good, they were sufficiently distinct to determine the form. They are shown in fig. 1.

The habits of the creedite are quite variable and are entirely similar to those found on the Creede mineral. The simplest combination is that of the prism and equally developed front and rear unit pyramid, giving the crystal an orthorhombic aspect. In another type the front pyramid is the predominant terminal form, the rear unit prism being reduced to small modifying faces. In a third type the basal pinacoid is the predominant end face, the front and rear unit pyramid and the front and rear unit domes being reduced to narrow and small modifying faces.

The mineral is biaxial negative with a medium large optic axial angle. Crystals lying on the orthopinacoidal face show the emergence on an optic axis nearly centered in the field. The dispersion is strong with ρ greater than v . The plane of the optic axis is in the plane of symmetry and the maximum extinction angle $Z \wedge c = 42^\circ$. The indices of refraction are as follows: $\alpha = 1.462$, $\beta = 1.478$, $\gamma = 1.483$.

The amount of material available did not suffice for a chemical analysis but the crystallographical measurements and the optical properties definitely place this mineral as creedite.

The creedite needles are plainly a secondary product, their genesis is related to the formation of the clay and wad. The association of the mineral at both Creede and Granite with fluorite and halloysite suggests that it results by the action of aluminum bearing solutions upon fluorite. The gold of the veins is primarily inclosed in the fluorite but some crystals of creedite were found with inclosed plates of gold, suggesting that the material of the fluorite was removed and its place taken by creedite. Whether this is a surface alteration or the results of late hydrothermal change cannot be determined from the material at hand.

The occurrence at Granite is the second reported locality for creedite but the deposits are of small importance and are now completely abandoned, so it is doubtful if many specimens are still obtainable.

NOTES AND NEWS

BIOGRAPHICAL NOTICE OF W. S. ANDREWS, A PIONEER IN THE STUDY OF THE LUMINESCENCE OF MINERALS

CHARLES PALACHE, *Harvard University*.

W. S. Andrews, a life long worker in the field of electric lighting, died in Schenectady, New York, on July 1, 1929, at the age of eighty-two.

Born at Saltford, Somersetshire, England, on September 10, 1847, he came to America in July, 1875, and on December 4, 1879, entered the service of Thomas A. Edison, at Menlo Park, New Jersey.

He was active in the design of parts of the early Edison carbon incandescent lamps, and of machinery for their manufacture, and also of many other components of the Edison system. In various positions of increasing responsibility related to the Edison Electric industries, he moved from place to place until in 1894 he went to Schenectady where he remained active for the remainder of his long life in the employ of the General Electric Company.

From 1897 to 1903 he experimented with x-ray tubes, obtaining a number of patents for their regulation and, due to the then unknown danger of x-rays, received severe burns on his left hand and face, from which he suffered thereafter, and they finally affected his hearing and caused him years of excruciating suffering and finally the loss of his eyesight. He may well be said to have died a martyr to the progress of scientific knowledge in this field.

About 1900 he became interested in the subjects of fluorescence and phosphorescence and the general subject of "cold light." His experiments in this field led to many papers dealing with this general subject, one of which, published in this journal,¹ described the preparation of synthetic fluorescent willemite and other luminescent compounds. The writer has previously made reference² to the very practical form of iron—spark apparatus which Mr. Andrews designed to make more generally known to the public the remarkable fluorescent properties of many substances both artificial and natural. This instrument is now used effectively in many mineralogical laboratories for mineral determination.

¹ *American Mineralogist*, 7, 19, 1922.

² *American Mineralogist*, 13, 1928, 330.

Through Mr. W. L. Lemcke of Franklin, Pa., the writer has learned that Mr. Andrews was one of the engineers who cooperated to effectively use ultraviolet light at the works of the New Jersey Zinc Company at Franklin, N. J., to control the concentration of willemite.

It is employed to examine the wet waste sand or "tailings" from the jigs in which that part of the ore not picked up by magnetic concentration is separated by gravity into its constituents. The tailings, chiefly calcite, may contain more or less of the valuable ore willemite. By holding the iron-arc over a car of tailings the workman can quickly judge by noting the number of points of light (willemite particles) on the surface whether the jigs are correctly adjusted to make the best possible concentration. It is a very rapid and useful check on the process. From this use the iron-arc soon found its way into the office of the chemist at the sampling laboratory and knowledge of the effect of ultraviolet light in producing fluorescence in minerals has now become widespread. Its use for museum display as exhibited in the mineral collections of the British Museum and of the Philadelphia Academy of Science has been described in recent publications.³

It is a satisfaction to be able to make known generally the fact that Mr. Andrews was a pioneer in the development to practical form of this beautiful and very useful instrument of science.

BOOK REVIEWS

LEHRBUCH DER ERZMIKROSKOPIE. HANS SCHNEIDERHÖHN, professor of mineralogy in the University of Freiburg and PAUL RAMDOHR, professor of mineralogy in the Technical High School in Aachen. Gebrüder Borntraeger, Berlin, 1931. Price \$17.50 (bound).

This monumental work on the microscopic study of the ore minerals in vertically reflected light is to comprise two volumes and an appendix consisting of determinative tables for ore minerals. At the present writing only volume II and the appendix have come off the press and this review applies only to the former. It contains 714 pages of text with 7 drawings, 235 photomicrographs in black and white and 4 photomicrographs in colors. The "Lehrbuch" can be considered a second edition of Schneiderhöhn's earlier work "Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen und Aufbereitungsprodukten, besonders im auffallenden Licht" which appeared in 1921. Volume I of the "Lehrbuch" will consist of the fundamental scientific principles of reflected light, description of the instruments and the methods of investigation. Volume II is a description of ore minerals and their microscopic properties.

³ *Am. Mineralogist*, **14**, 1929, 33 and 362.

This volume is a systematic descriptive mineralogy of the ore minerals, with some of the more important gangue minerals, such as quartz, the carbonates, augite and hornblende. The sequence of the minerals follows in general that of the tables of Groth-Mieleitner modified in accordance with recent chemical and microscopic observations.

The authors have arranged the data for each mineral in a definite sequence and since in the past no definite system has been followed by the individual investigators, they strongly suggest that in the future others follow the same plan they have used. The scheme is as follows:

I. *General Properties.* The chemical formula, crystallography, crystal lattice, and physical properties are given according to the most reliable data.

II. *Preparation of Polished Section.* No general directions for grinding and polishing all ore minerals can be given; each mineral must be considered by itself. The procedure most suitable for the mineral under discussion is given under this heading.

Two properties of cohesion are referred to which serve as important diagnostic properties, namely, polishing-hardness and polishing-cleavage. Polishing-hardness manifests itself in varying relief of the different minerals on the surface of the section. Polishing-cleavage, as developed by polishing, is at times essentially different from the cleavage observed in the hand specimen. Often well-developed macroscopic cleavage fails to appear after polishing. The authors believe that a smearing of the surface caused by the polishing agent is the cause for this non-appearance.

Precautions are given for avoiding chemical changes in certain minerals caused by imbedding in sulphur-containing plastolin, or during impregnation in Canada balsam.

III. *Power of reflection, color, and reaction to polarized light.* The color of the mineral as seen in the reflecting microscope is described as completely as possible. This has been found to vary widely, in a subjective sense, according to what other mineral or minerals adjoin the mineral in question. For this reason the apparent color is given when the adjacent mineral closely resembles, and is apt to be confused with the mineral in question; also the apparent color is given when in contact with certain standard minerals such as galena, sphalerite, pyrite, chalcopyrite, pyrrhotite, etc.

The absolute reflective power, that is, the proportion of incident light that is reflected, is given both in air and in immersion oil, index 1.505. These values were obtained by means of a photometer ocular designed by M. Berek. Similar relative values were obtained by J. Orcel by means of a specially constructed photo-electric cell. Orcel's values for relative reflection are based on galena as a standard.

The most valuable data on anisotropism are brought out by observation in reflected light with crossed nicols, and must be made with a very strong light source. According to Berek, reliable quantitative data cannot be obtained by this method, which corresponds to the observation of the reviewer. The authors give empirical designations for the anisotropic effect as: very weak, weak, well recognizable, strong, extremely strong. These are, of course, not exact quantities and correspond to the authors' own impressions. The authors also give the colors as seen under crossed nicols, both in air and in immersion oil. (Herein the reviewer differs from the authors and from American scientists, such as Bateman and Farnham, in that he believes that the colors of most minerals observed under crossed nicols are modified largely by the source of light, the optical system and condition of the microscope, and es-

pecially by the amount of rotation of the analyzer from the crossed position. For minerals of very strong anisotropism or peculiar polarization colors, such as covellite and arsenopyrite, these colors can be described and duplicated by separate observers; but for the great majority of minerals approximate degrees of variation in intensity are all that can be described with assurance. The authors say almost nothing about the advantage of rotating the upper nicol a few degrees (Sampson's method) which in the reviewer's opinion is vastly superior to the 90° (or exactly crossed) position of the nicols.

IV. *Etch Behavior.* The usual etch tests, which have been made use of by Murdoch and by Davy-Farnham for the determination of ore minerals, are given in this section. Certain drawbacks to this method, such as the electrolytic effects set up when a drop of reagent covers two or more adjacent minerals, are emphasized by the authors. When a single mineral occupies the section the results obtained by different observers check fairly well. The etch-cleavage and blue color produced on chalcocite are specific tests for that mineral; likewise the yellow coating produced on stibnite by KOH. "But in most cases the reactions described as 'tarnishes', 'dissolves', 'gives a precipitate' etc. are so dependent upon unforeseen factors that no reliance can be placed upon them. We have, therefore, from the start given up attempts to further this method of obtaining definite properties and warn all against too much dependence on this method of determination."

The present writer takes issue with the authors on this somewhat sweeping statement. With experience in manipulation and observation, surprisingly consistent results are obtained by the systematic etching scheme. The electrolytic effects so emphasized by the authors can be noted for definite mineral associations, but it is the reviewer's belief that these effects are so small with most mineral associations as to be negligible. The platinum loop with which the drop is applied can be made as small as 0.6 mm. diameter and even with complex intergrowths, areas of the unknown mineral can be found with greater diameter. As long as the boundary is not spanned by the drop the electrolytic effect can be neglected entirely.

A different type of etching is strongly favored by the authors, that is, structure etching. It has for its goal the development of an etch fluid for every ore mineral which will bring out the following:

1. The inner nature of the crystal grains (twinning lamellae, zones, deformations). This is termed "internal grain etching."

2. The different degree of attack in different crystallographic directions, since the individual grains in the aggregate are oriented differently. It cannot be sharply separated from 1. This is termed "grain surface etching."

3. The grain boundaries of the individual crystals in the aggregate or "grain boundary etching."

Etch fluids which the authors hope will fulfill these conditions for every mineral are to be described in the forthcoming volume I.

V. *The inner nature of individuals.* The most widely occurring surfaces within a crystal grain are twinning lamellae, which are extraordinarily widespread among ore minerals. The authors differentiate between the different types of twinning as follows: growth twinning, resulting from the formation of the mineral; pressure twinning resulting from the effect of external pressure; and transformation twinning, which results from the change of temperature whereby the mineral passes through an allotropic transformation point.

The authors observe that "Deformations are extremely abundant among ore minerals. . . . They manifest themselves in undulating extinction, warping, translation and glide twinning formations, finally cataclasis in all stages. All these phenomena signify that either the space lattice is under external pressure or that the 'free surface' has become very great." Unmixing phenomena are also considered in this section and the authors have widened our knowledge of these structures very materially. They have been produced experimentally by Lombard, Merwin, Greig, Schwartz and Bateman in this country.

Structures formed by replacement are also discussed and the authors make the following observation which is fully justified. "One must avoid judging as such all forms which at first glance seem to indicate replacement. This has been done too often in the literature."

VI. *Structure and Texture*. The authors do not attempt to describe systematically all the textures and structures that can occur in ore deposits, but they have made all possible observations with the idea of publishing in the future a text book on ore deposits.

Special textures considered are gel-textures which, they state, can form not only at temperatures below 100° but also in molten fluids. Replacement structures are considered in detail and where possible the ascending or descending origin of the replacement is determined.

Intergrowths with other minerals are considered which do not of themselves prove replacement. Such are the widespread "graphic", "eutectic", "myrmekitic" intergrowths, also "mutual boundaries."

VII. *Possibility of confusion with other minerals and recognition*. In this section are given minerals which are apt to be mistaken for the mineral in question, and criteria for distinguishing between them are described.

VIII. *Position in a classification of ore deposits and paragenesis*. The authors have attempted to classify every polished section as far as possible with regard to its position in a systematic classification of ore deposits, especially that set up by Niggli and Schneiderhöhn in 1926. This was only carried out in part in the work under review but they expect to use the abundance of observations already made in a future textbook.

Finally a partial list of localities in which the mineral occurs is cited. The localities chosen are for their value from a genetic rather than an economic standpoint.

IX. *Literature*. References to the literature are collected at the end of the book. The list comprises not less than 618 separate articles. To the reviewer this list constitutes one of the most valuable portions of the book, especially for North American geologists, for many articles are cited which cannot be found in by far the greater number of libraries available to them. There are a surprising number from the geological and mineralogical publications from such countries as Norway, Sweden, Finland, Russia, Austria, Holland, Japan, China and many others. The authors have combed the literature with admirable thoroughness.

* * *

The book is printed on paper of exceptionally good quality, and this permits the reproduction of details in the illustrations with the greatest fidelity. The photomicrographs are carefully selected and are given for nearly every mineral described. They are superior to nearly all those in American scientific magazines not only because of the better quality of the paper but also because of the unusual size of the

pictures themselves. The largest of these measures 8×11 cm. and the smallest 5×6 cm.

The amount of space given in the text to each mineral varies with the importance of the mineral and the quantity of data available. Schapbachite, for instance, takes up little less than one page, whereas chalcocite covers 24 pages. The price of the book, \$17.50 for a bound volume, places it beyond the reach of the average student.

That the authors are perhaps fully aware of the importance of their own work appears from the following statement: "Beide Verfasser Können wohl ruhig sagen, das sie zusammen mehr erzmikroskopische Beobachtungen gesammelt haben und mehr Anschliffe durchmikroskopiert haben, als es irgendwo sonst der Fall sein wird. Ungerechnet die Schliffreihen aus Einzellagerstätten, die in Spezialarbeiten untersucht wurden, haben beiden Verfassern etwa 6000 systematisch ausgewählte Anschliffe von den verschiedensten Lagerstätten der Erde zur Untersuchung vorgelegen."

It should be stated, in conclusion, that this book is unquestionably one of outstanding excellence and should at least be on the reference shelf of every institution where economic geology is taught, and thus be available to all students of ore deposits.

M. N. SHORT

ERZMIKROSKOPISCHEN BESTIMMUNGSTAFELN. Appendix to Lehrbuch der Erzmikroskopie, H. SCHNEIDERHÖHN AND P. RAMDOHR. Gebrüder Borntraeger, Berlin, 1931.

The Determinative Table is an appendix to Volume II but is bound under separate cover. It contains 4 pages of explanatory material and 42 pages in the table proper. Minerals in this table are arranged in accordance with their qualitative and not quantitative characteristics. The only quantitative data used are the relative reflective values for the minerals. As these determinations involve a rather expensive apparatus, they are not used as a basis for main subdivisions but are given in the incidental data. The principal properties on which minerals are arranged are: A—Hardness, B—Behavior toward polarized light, and C—Color. The arrangement according to hardness is as follows:

- I. Soft, or minerals softer than galena.
- II. Medium, or minerals harder than galena and softer than pyrrhotite.
- III. Hard, or minerals harder than pyrrhotite.

These main divisions are in turn divided into subdivisions on the basis of their reactivity toward polarized reflected light as follows:

1. Isotropic.
2. Weakly anisotropic.
3. Strongly anisotropic.

There is no hard and fast line between 2 and 3 but in general if the effect is only apparent with strong illumination and reflection pleochroism is absent, the mineral is considered as weakly anisotropic. If a mineral shows the effect with moderate illumination, and especially if reflection pleochroism is present, the mineral is strongly anisotropic.

The three main divisions, each with three subdivisions comprise nine groups or classes. Each of these is in turn divided into three sub-groups on the basis of their color in reflected light as follows:

(a) Pure white, closely resembling galena.

(b) Slightly colored, "not decidedly colored, but in direct comparison with galena, especially by means of the comparison ocular, clearly different as seen by color-sensitive eyes."

(c) Strongly colored, clearly recognizable as colored, even without the comparative ocular.

The result of the foregoing scheme is 27 "pigeon-holes." The descriptions given for each mineral are necessarily very condensed from those in Volume II. The mineral names are arranged in a column at the left-hand border of the page and the data are given in compartments successively to the right in the following order: reflective power, color internal reflection, cohesion (cleavage, etc.), elements present, etch tests (according to Murdoch and to Davy-Farnham), special characteristics, and page reference (referring to Volume II where a more detailed description is given).

These data are arranged so effectively that for most minerals three or four horizontal lines suffice to complete the description. The "pigeon holes," as might be expected, vary in the number of minerals which they contain. For instance I. 3.b (Soft—strongly anisotropic—slightly colored), contains 21 minerals, whereas III. 2.c (Hard—weakly anisotropic—decidedly colored), contains only one mineral, ludwigite, $3 \text{ MgO} \cdot \text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{B}_2\text{O}_3$. The book is of convenient size, 7×10 inches (approx.) and the descriptions are printed only on the right hand pages, giving the user plenty of blank space on which to record additions or corrections.

The scheme is indeed an ingenious one and were it possible to make the distinction required, it would fulfill the purpose for which it was intended. There are, however, some factors which militate against the effectiveness of the scheme as they do against any scheme of pigeon-holing minerals; by far the most important is the large number of minerals which approximate in their characteristics the boundaries between successive pigeon-holes. In the above scheme if a mineral is very soft, it is very difficult to determine whether it is softer or harder than galena. Such a distinction is difficult even with the Talmage hardness instrument. Similarly even the experienced observer will find it difficult to decide whether a mineral is galena-white, or whether it is significantly more colored than galena. By setting up such a criterion the authors have in large measure reverted to the original scheme of Murdoch which relied upon separation of delicate shades of color for subdividing minerals. The authors in part avoid the difficulty by stipulating the use of the comparison ocular. This is expensive in itself and requires an additional metallographic microscope, which constitutes a serious objection in any general determinative scheme. American microscopists, after some years of experience with Murdoch's textbook, were almost unanimous in their opinion that delicate color distinctions should not be made the basis of a determinative scheme for ore minerals.

The appendix is an essential feature of the authors' work and is a valuable reference book for all who are interested in ore minerals.

M. N. SHORT

Correction

The reader is asked to make the following corrections in the article "On the Triclinic Manganiferous Pyroxenes" which appeared in the October and November issues of the Journal. On page 411, fourth line from top, " MnSiO_3 " should read MgSiO_3 . Also pages 510 and 511 have been transposed. Page 511 should be numbered 510, and 510 should be 511.